Invited Paper

GaN HEMT Lifetesting – Characterizing Diverse Mechanisms

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Because GaN HEMT is a relatively new technology, there is still a variety of distinct degradation mechanisms present in devices from most laboratories. Therefore it is not sufficient to simply lifetest them till they fail – one must measure all the competing mechanisms, and determine their net effect at the end of the mission life. This contrasts markedly with the present-day situation for GaAs-based technologies, where the devices from a given laboratory wear out by only one well-characterized mechanism. In this paper, we illustrate why simple lifetesting is not sufficient, and briefly outline a technique (based on standard lifetest methods) that allows one to develop a picture of the various mechanisms, and their contributions at any time and temperature.

The problem is illustrated in Figure 1, which is a hypothetical Arrhenius plot for a GaN technology. Here the 3 black dots on the “Thermal Effects” line indicate the MTTF’s measured in a typical elevated-temperature DC lifetest, which is most sensitive to thermal degradation mechanisms. At these high temperatures it is the thermal effects that cause failure first. Then, extrapolating these data to a typical use temperature (say 110 °C) we read off an MTTF of 2×10^6 hrs, which is reasonable for some applications. But we notice that at the use temperature, other mechanisms may actually cause failure before the thermal effects: electron trapping effects will be fatal at about 4×10^4 hrs, and even if these can be tolerated, hot electron effects could cause failure at 3×10^5 hrs. Thus, while one effect may occur first in accelerated tests, it’s very important to characterize other mechanisms that may be present. And this is true whether one is lifetesting with DC stress alone, or with RF operation as well – to get meaningful E_a’s for extrapolation to mission temperatures, one must be distinguish the various mechanisms.

Our technique involves the following principles:
1. Choose “targeted” DC stress conditions where one mechanism is strong. (See Figure 2 for some hypothetical choices.)
2. Monitor a parameter that is only affected by one mechanism. We call this the “signature parameter”. Examples:
a) Sudden, irreversible Ig increase - a symptom of critical Vdg.
b) Electroluminescence under forward bias.
3. Conduct separate DC lifetests to characterize each mechanism.
4. Conduct an RF lifetest, to scale the rates of degradation in the targeted DC lifetests to the rates expected in typical RF operation.

This approach has the following adavantages:
1. We study each mechanism with biases where that mechanism is strong.
2. We use mostly DC lifetests (simple and economical), and only one RF lifetest (complex and expensive).
3. If we move to another application with different RF biases or frequency, we only need to repeat the RF lifetest.

We show some results with a 2011-vintage GaN HEMT technology with 0.15 µm gates and no field plates. The only observed degradation mechanisms were:
1. Surface pitting and associated extended defects beneath them, with signature parameter δI_{dmax}, maximum drain current, measured with µs pulsing.
2. Hot electron damage, with signature parameter δG_{mp}, the peak of the transconductance, plotted against V_g.
3. Electron trapping, with signature parameter δV_{th}, the threshold voltage.

The failure criterion was 1 dB drop in the output power, at 62 GHz. DC lifetests were conducted on single transistors, and RF lifetests were conducted on 1-stage amplifiers.

Figure 3 shows an example of DC lifetest results, and the corresponding RF stress results, used to scale the MTTF to RF operating conditions. Figure 4 shows the Arrhenius plots for the various DC lifetests, with scaling applied. Figure 5 shows the overall Arrhenius plot for failure of the RF operation, with the curves for each of the mechanisms. We see that surface pitting defines the reliability at most temperatures, but below about 80 °C electron trapping will probably cause failure first. We note that if the surface pitting vulnerability is reduced with process improvements, it is quite likely that one of the other mechanisms will then dominate the reliability.

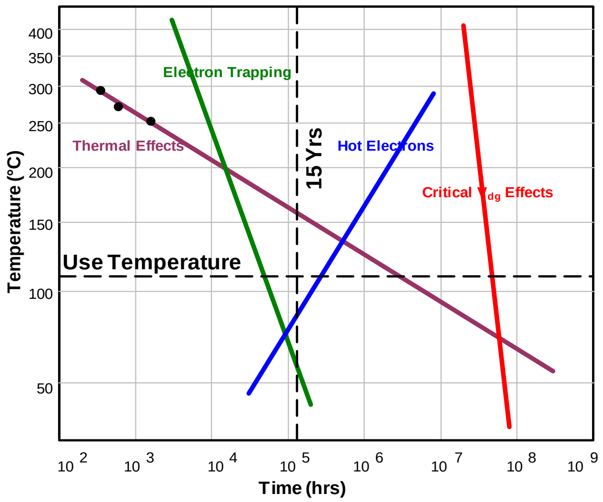

Fig. 1. Hypothetical overall Arrhenius plot

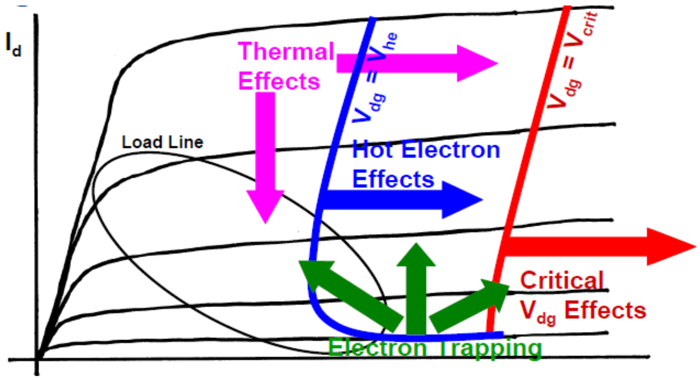

Fig. 2. Hypothetical bias zones for characterizing various mechanisms.

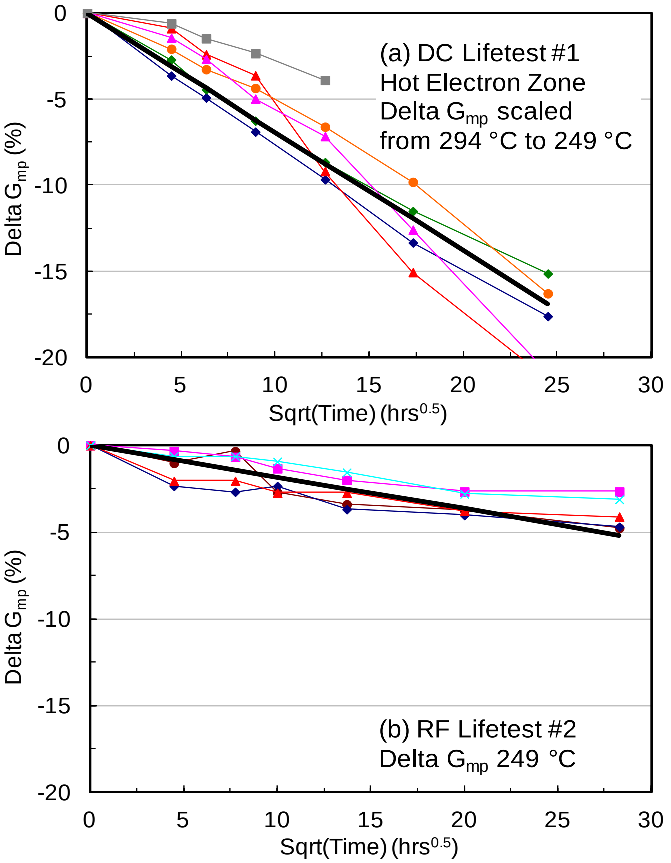

Fig. 3. Examples of lifetest data, illustrating the different rates measured in DC and RF lifetests.

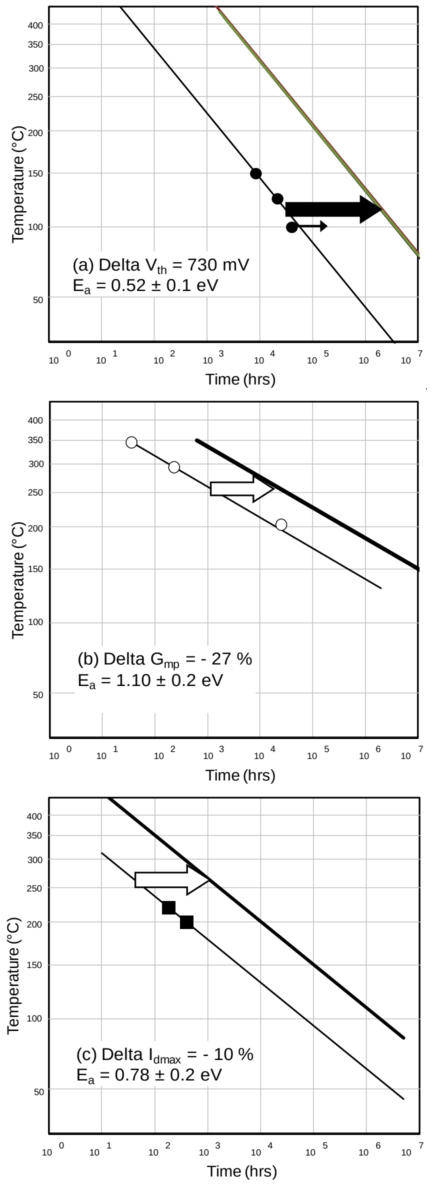

Fig. 4. Measured Arrhenius plots for various mechanisms, showing scaling to RF operating conditions.

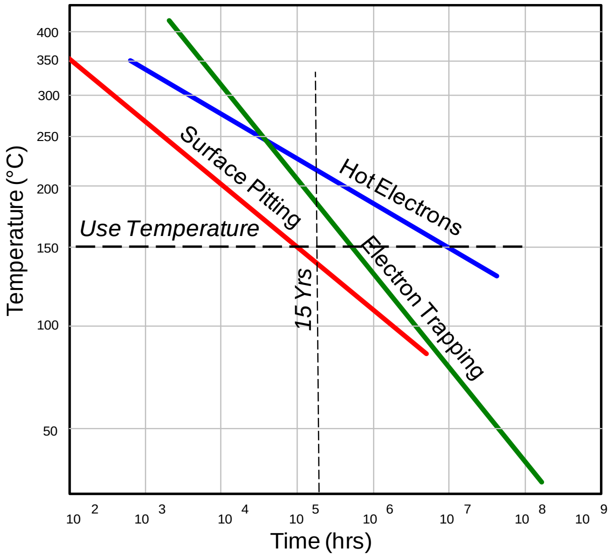

Fig. 5. Actual overall Arrhenius plot for one GaN HEMT technology.